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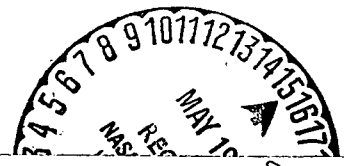

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THE WATER BATH AS A PARTIAL SIMULATOR FOR WEIGHTLESSNESS IN SPACE MEDICINE

by

Heinz von Diringshofen

The human body immersed in water loses weight due to buoyancy. In the unpowered phase of a space flight, as in free fall or a free orbit, every body is weightless. Thus, it is understandable that space medicine uses the water bath for simulation of space flight in the laboratory. /307*

But weightlessness can be simulated only partially in this way. The otoliths retain their weight even in swimming under water. Furthermore, the hydrostatic pressure of the water on the immersed human body causes changes in the venous return from the abdominal cavity, with effects on the circulatory regulation. It also makes inspiration more difficult and expiration easier. These are effects which are lacking in true weightlessness.

In this respect, see the work of H. von Diringshofen on the mechanical effects of the water bath as causes of a parasympathetic alteration [1].

With appropriate consideration of its hydrostatic effects, the water bath is suitable for study of the effects of long-term elimination of the body weight.

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* Numbers in the margin indicate pagination in the original foreign text.

Such investigations were carried out from the space medical viewpoint in the USA by A. Graybiel and B. Clark [2] in the U. S. Navy School of Aviation Medicine, and also by E. Graveling, B. Balke and coworkers [3] at the U. S. Air Force Aerospace Medical Center at San Antonio, Texas. The former experiments were done with several subjects wearing only bathing trunks. They lay for 2 weeks in a water bath with physiological sodium chloride concentration, interrupted only two hours daily for bed rest, eating, and brief hygienic functions.

The studies of Graveling et al. were done with only one subject, who wore a water-tight suit for 7 days immersion. The stay was interrupted only 60 minutes daily for hygiene and measurements. In these experiments the water temperature was held constant at 33.5°C.

The subjects in the 2-week experiment lay as in a normal bath, but with a comfortable head pillow, on a woven mat in water that reached above the shoulders. In the 7-day long-term bath, the subject lay on a type of deck chair. The results of these space medical long-term immersion experiments were the following.

Pulse and respiratory rate, basal metabolism and body temperature remained rather constant.

/ 308

The systolic and diastolic blood pressure decreased gradually with the amplitude remaining about the same. (Unfortunately, the values were not given.)

In the first 5 experimental days of the 7-day experiment the EKG showed an increasing lowering of the T-wave, but it regained its initial height during the 6-th and 7-th experimental days.

The urine excretion increased from 1 - 1½ liters to about 3 liters on the 1st and 2d test days, and then on the 4-th day decreased to 1.7 liters. The excretions were 2 liters on the 5th and 6th days, and 1.5 liters on the 7th days. The thirst corresponded to the urine excretion at the time.

Nitrogen excretion increased from 2.5 g to 17 g in the first 24 hours. It was 13 g on the 3rd day and then decreased to 5 g on the 7th day.

Phosphate excretion reached about twice the initial value, with 5.7 mg on the 5th day.

(During the 5-week study period, the test subjects were fed only a puree of a nutrient powder, "Sustagen", which contained all the required nutrients and calories.)

In the blood picture, the leucocyte number increased from 7,250 to about twice that. The erythrocytes increased from 5.4 million on the 3rd day to 6 million and then decreased to the initial value again on the 5th day.

The blood serum protein content increased from 7.11 γ% to 7.8%.

The serum albumin concentration and the γ-globulin increased only up to the 3rd day. After the 5th day it decreased again to the initial value.

Certainly these changes have little to do with the weight-eliminating effect of the water bath, but are rather predominantly due to its hydrostatic pressure. The results are of interest for balneologists. It can be assumed that there are similar observations since the time when water beds were used for persons

with spinal injuries.

Considerably more informative for space medicine are the increasing appearances of physical and psychic asthenia established in the long-term bath, with a weakness of regulation in respect to the orthostatic effects of gravity in the circulatory system due to the long stay in a hypodynamic environment.

Here the elimination of the body weight in water is the main cause of the debility symptoms, which we also can observe in patients after long strict bed rest. In the long-term bath, perhaps, this debility is also strengthened by the parasympathetic effect of stimulation of the vagus nerve endings in the right auricle due to a rise in the venous inflow pressure from the Vena cava inferior (in the sense of the Jarisch-Bezold reflex).

All the test subjects in the space-medical long-term bath experiments showed a tendency to orthostatic collapse if they were placed in the vertical position on a tilting table outside the water. This tendency increased with the duration of immersion. In the 7-day experiment, after 50 hours in the bath, the pulse rate in that case increased within 3 minutes to 150 per minute; and after 7 days, it rose to 160 per minute. The blood pressure amplitude decreased, at the same time, to 15 mm Hg and, at the end of the experiment, to 7 mm Hg, with a decrease of the systolic and increase of the diastolic blood pressure.

/309

This tendency to orthostatic collapse was still distinctly present 2 days after the long-term bath.

Eleven hours after the 7-day long-term bath, the tolerance to acceleration in the head-buttocks direction was tested on a centrifuge. The tolerance was not decreased with respect to the occurrence of visual disturbances, but the test subject sensed

the acceleration as considerably more stressing than in a previous control experiment. Also, the increase in pulse rate was raised by the acceleration stress and nausea occurred.

This surprising tolerance to acceleration argues that the strong muscular tensions in the acceleration stress act to raise the blood pressure even after the long-term bath.

The muscular force was not diminished after either the 7-day immersion or the 2-week experiment. But the body capacity (measured by the maximum O_2 uptake in a bicycle ergometer experiment) was decreased by some 25T.

The psychomotor capacity was most diminished by the long-term immersion. This was expressed particularly distinctly in the first 45 minutes after leaving the bath, in a considerable uncertainty and delay in reaction time measurements of different types.

The requirement for sleep was considerably decreased in the hypodynamic environment. Deep sleep demonstrated in the electroencephalogram occurred on the average for only 2 hours. But the subject was often in a state of drowsiness and half-sleep.

Now if we consider these debilitating effects of weight elimination in the long-term bath in relation to space travel, which in the reentry phase not only produces the effect of high accelerations but also poses high requirements for the reaction capability of the crew, they could make us quite pessimistic about long space flights if the astronauts have no possibility for active exercise of their skeletal musculature during weightlessness.

In the weightless state, all the muscular tensions for maintenance of equilibrium disappear, and no circulatory regulations are needed to compensate for orthostatic pressure differences in the vascular system. But there remain sufficient possibilities for muscle training and, therefore, for appropriately stressing the regulators of the blood circulation, including the presso-receptors.

To be sure, some tonicizing of the skeletal musculature is lacking from the otoliths in weightlessness.

On 7 August 1961 the Soviet space pilot Tötov demonstrated that a human can stand 25 hours of weightlessness in space flight and then negative accelerations of 6 - 8 times gravity on reentry into the earth's atmosphere without serious disturbance.

In the opinion of the Soviet space physician, Prof. Jadovskiy, Tötov's long stay in the weightless state caused a disturbance in the labyrinthal functions which, as in air and sea sickness, led to nausea, vertigo, and, with Titov, even to nystagmus. From the sparse reports on his space flight we can find that after removing his safety belt he tested free floating in the spaceship cabin. If he performed rotations about his body axis somewhat too quickly, moving his head at the same time, he could produce strong labyrinthal stimuli from Coriolis accelerations. These produced severe nausea phenomena. /310

For Titov, these phenomena decreased gradually after sleep and had entirely vanished before ignition of the braking rockets to start reentry into the atmosphere.

His good sleep during the space trip is partly a sign of his good "nerves", but it could also be explained by the previous severe psychic stress as well as by a vagal adjustment in the weightlessness state due to the absence of tactile stimuli caused by gravity.

Certainly a space flight lasting for many days must lead to a critical decrease in physical and psychic capability if the debilitation due to weightless is not counteracted by appropriate gymnastics.

Rapid back-and-forth movements of the extremities are suitable for this, where the muscular force must accelerate the mass of the limbs and stop it again.

We can also consider work against elastic resistances (Expanders) or overcoming of frictional resistance (as in turning a hand mill).

Long-term immersion experiments, again, can be useful for testing the effectiveness of such muscle exercises in preventing debility.

From bed gymnastics it is known that even relatively brief and light daily muscular work is sufficient to prevent muscle atrophy. We can even consider the use of massage here.

Inflatable cuffs over the upper and lower legs and over the abdomen, such as pilots use to stand accelerations better, could also "train" the function of the pressoreceptors by their effect of raising the blood pressure. A temporary under-pressure and over-pressure respiration could also be considered for such training.

These few references may suffice to indicate the range of overlap of space medicine and physical therapy.

Now I would like to report briefly on some space medical studies on underwater vertical orientation, which were done in the USA by L. A. Knight [4] and J. L. Brown [5] in relation to

the partial simulation of weightlessness in a water bath.

Knight wished to investigate whether the socalled "blind spot" of the otolith function, described by Quix in 1928, could be utilized for better simulation of weightlessness in a water bath.

In his studies, the subject lay on a tilting table in about 2 m depth of water and breathed with a well balanced diving apparatus. Oblique positions up to some 100° deviation from the vertical position could be reported with 8 - 18° accuracy. In the/311 vertical position with head down, the error in reporting position was as much as 100 degrees of angle.

In Brown's underwater experiments, the test subject (with diving equipment) at a depth of 6 - 7 m and in a rolled-up position was rotated several times on a turntable at an angular velocity of 2 - 5 rotations per minute and then held in a certain position. He was then required to point vertically upward with his hand. The errors were as much as 180° if the test subject was stopped with his head down. The accuracy of vertical orientation could be considerably improved by active head motions after the rotation.

On the basis of these results, the author recommends for partial simulation of weightlessness in the water bath, a rearward tilt of the subject's head by 135° from the vertical, as well as the avoidance of head motions, so that there is as little stimulation of the otoliths as possible.

In the Italian underwater experiments on weightlessness of Prof. Margaria, the spatial orientation with eyes closed was at first very inaccurate. But it improved with practice, and finally reached almost the same accuracy as outside the water.

This observation suggests that normally the otolith organs play only a subordinate part in vertical orientation, as long as the other gravireceptors are sufficient for it, but that the use of their function can be trained.

Accordingly, one must not overestimate the failure of the otolith function in true weightlessness.

My explanations are intended to illuminate the relationship of space medicine with balneology and physical therapy with some spotlights for you. Through the long-term immersion studies for partial simulation of weightlessness, and through studies on the increase of acceleration tolerance in a water capsule, space medicine, the youngest branch of medical science, is linked with balneology, the oldest medical healing art.

Both areas of knowledge can mutually supplement and stimulate each other.

Balneology has the greatest experience, and space medicine has the greatest support at present in the USA and the USSR.

We stand at the beginning of joint European efforts in space flight research. Predictably, the interest in your circle about space medical problems will increase.

I greatly regret that I was prevented by an unexpected urgent commission from presenting this report personally and being available for a discussion.

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16. Abstract
Experiments using the water bath for simulation of space flights in the laboratory are described. The mechanical effects of the water bath as causes of a parasympathetic alteration. Experiments revealed a tendency to orthostatic collapse in long experiments, with the tendency increasing with duration of immersion.

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